STUDY ON THE ALKAI FUEL ASH IN FLY ASH
BASED GEOPOLYMER CONCRETE CONTAINING OIL PALM SHELL

MUHAMMAD AIFA BIN MOHAMAD SUHAIMI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Civil Engineering

Faculty of Civil Engineering & Earth Resources
UNIVERSITY MALAYSIA PAHANG

JUNE 2013

ABSTRACT

Malaysia as the world's largest exporter of palm oil has been facing problems- in disposing palm oil fuel ash, a by-product of palm oil mill since many years ago. Through public concerns and research efforts, the agrowaste by-product materials Have potential to be utilized as construction material to replace conventional ordinary Portland cement (OPC). In this study, the effectiveness of agrowaste ash by-product namely palm oil fuel ash (POFA) and oil palm shell (OPS) were developed as an alternative, materials to replace the OPC. POFA fly ash-based concrete is a concrete produced by integrating POFA as a pozzolan in concrete. The quality of POFA was improved by grinding until the median particle sizes were 50 microns. POFA was replaced fly ash by 0%, 10%, and 20%, whereas OPS were replaced sand by 12.5%. The compressive strength of POFA-concretes due to 1, 7, and 28 days of curing ages of different temperature were investigated. The temperatures involved in this experiment were room temperature, 60°C and 80°C. In addition, the porosity of geopolymer concretes fly ash based also was assessed. The results revealed that the compressive strength of geopolymer concrete by the addition of POFA was much lower than that of geopolymer concrete without POFA. The control mixtures for this experiment have the high compressive strength compare to the mixtures added with POFA for all the curing temperature. However, the replacement of POFA by 20% recorded the highest in strength compared to 10% POFA replacement. It is recommended that the optimum replacement levels of POFA are 20% mixture for a good strength in compressive test.

Keywords: POFA, OPS, fly ash based

ABSTRAK

Malaysia sebagai salah satu negara pengeluar minyak kelapa sawit terbesar di dunia telah mengalami masalah penglupusan abu minyak kelapa sawit, iaitu produk sampingan dari kilang minyak kelapa sawit semenjak bertahun lalu. Melalui kesedaran awam dan usaha-usaha kajian,bahan buangan pertanian ini dikenalpasti mempunyai potensi untuk dijadikan sebagai bahan pembinaan untuk menggantikan *ordinary Portland cement* (OPC). Di dalam kajian ini,keberkesanan abu bahan buangan yang dinamakan *palm oil fuel ash* (POFA) dan *oil palm shell* (OPS) ini dijadikan sebagai bahan alternative untuk menggantikan OPC. Abu konkrit POFA ialah konkrit yang terhasil dari pengintegrasian POFA sebagai pozzolan di dalam konkrit. Kualiti POFA ditingkatkan dengan pengisaran sehingga saiz zarah median adalah 50 microns. POFA menggantikan abu sebanyak 0%, 10% dan 20% manakala OPS menggantikan pasir sebanyak 12.5%. Kekuatan mampatan konkrit POFA dari hari ke 1, 7 dan 28 proses *curing* dengan suhu yang berlainan dikaji. Suhu yang terlibat di dalam kajian ini adalah suhu bilik, 60°c dan 80°c. Tambahan pula, keliangan asas abu konkrit geopolymer juga turut dikaji dan keputusannya menunjukkan keliangan asas abu konkrit geopolymer dari tambahan POFA adalah lebih rendah dari keliangan abu konkrit geoolymer tanpa tambahan POFA.Campuran pengawalan ujikaji ini mempunyai tahap kekuatan mampatan yang tertinggi berbanding dengan campuran-campuran yang ditambah POFA untuk semua suhu *curing*. Walau bagaimanapun, penggantian POFA sebanyak 20% merekodkan kekuatan mampatan yang tertinggi berbanding dengan penggantian POFA sebanyak 10%. Adalah disyorkan bahawa tahap penggantian optima POFA ialah campuran 20% untuk kekuatan yang terbaik di dalam ujian mampatan.

Kata kunci: POFA, OPS, fly ash.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

OPC	Ordinary Portland cement
OPS	Oil Palm Shell
ASTM	American Society for Testing and Material
POFA	Palm Oil Fuel Ash
SiO_2	Sodium Silicate
Al_2O_3	Aluminum Oxide
Fe_2O_3	Iron (III) Oxide
Si	Silicon
Al	Aluminum
NaOH	Sodium Hydroxide
CO_2	Carbon Dioxide
Na_2O	Sodium Oxide
RHA	Rice Husk Ash
XRF	X-Ray fluorescence

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the era of globalization, technology has grown to be more sophisticated. With the growing needs and faced with limited resources have forced people to innovate on existing technologies. The man should be creative to face the challenges of globalization to create something using various alternatives. In the context of the building, something can be done to reduce costs, improve the strength of the building, and increase the lifespan of the building.

Usually, for concrete mixing, Ordinary Portland Cement (OPC) is used. OPC is indeed very widely used in the present age. It has proved to be able to strengthen the structure of the building. But when facing the challenges of globalization such as the cost of materials and natural disaster-prone cause people to think to modify the resulting concrete structure to be compatible with the current situation.

One of the ways that can be done is to produce geopolymer concrete. The reaction of a source material that is rich in silica and alumina with alkaline liquid will produce geopolymer concrete. With the rapid growth in terms of population, development of technology and industry, as well as social civilization became a factor of the demand in the construction of buildings in the rural sector, estate, and urban city. Due to the use of concrete as a main material for construction so we are not able to avoid the depletion of natural stone that cannot be renewed. One of the ways to reduce or replace natural stone to make concrete is to use the OPS. OPS are stand for Oil Palm Shell which is the solid waste from the agricultural sector.

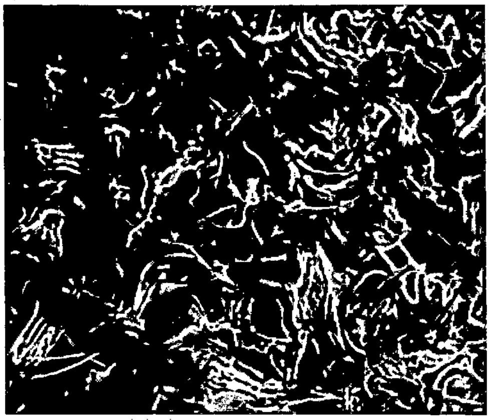

Figure 1.1. Oil Palm Shell

"It must be noted that nearly 80 per cent of the resources used today in construction industry are non-renewable. Due to the scarcity of conventional raw materials, there is a great opportunity to explore the alternatives of renewable resource such as oil palm shell (OPS) solid waste from the agricultural sector" (Associate Professor Dr Md Abdul Mannan, 2010). When OPS are being used for concrete production, more building can be built as alternative for various group of people. It can be used to replace the natural course aggregate in concrete production. The precast reinforced concrete product can be made using conventional concrete (normal weight concrete) and lightweight concrete by using oil palm shell which is the solid waste from palm oil mill. "It is structurally efficient and is recommended for use in modern buildings." (Associate Professor Dr Md Abdul Mannan, 2010). OPS aggregate has a unit weight of 500-600 kg/m^3 and this is approximately 60% lighter compared to the conventional crushed stone aggregates. So, the produce concrete will be lightweight. Before the OPS was used as aggregate, it was sieved and only aggregate passing through the 12.5 mm sieve and retained on the 4.75 mm sieve was used.

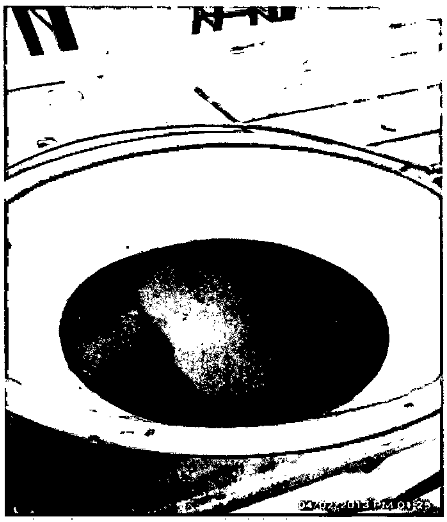

Figure 1.2. Palm oil fuel ash

Lightweight concrete generally has a density less than the density of 2000kg/m^3 and concrete OPS dropped at this stage. OPS concrete is 20% lighter when compared to normal weight concrete with a density of 2400kg/m^3. This proves OPS concrete can reduce 20% dead load when used in construction. By reducing the normal weight the structure, the earthquake's force and the force of inertia can also be reduced because of this pressure is directly proportional to the weight of the structure.

Ground POFA can be successfully used as a good pozzolanic property. Tonnayopas *et al.* (2006) who is researcher used of 5-30% ground POFA by weight of OPC and found that incorporation of POFA in concrete decreased the strength at early ages at 3 to 21 days, but the strength achieved at after 28 days for the concretes with 5 – 15% POFA met the ASTM C618 requirement (ASTM C618-08a 2008). Chindaprasirt *et al.* (2007), also a researcher used ground POFA in concrete and found that POFA has a good potential for concrete production.

There are two type of POFA which are ground and unground POFA. Its different in term of color, specific gravity, median particle size, specific surface area, strength activity index and soundness. Usually unground POFA is light grey in color due to unburnt carbon content left at relatively low burning temperature. When the burning temperature is high the unburnt carbon content will become very low. For the ground POFA the color become dark grey. The unground POFA have a specific gravity of 1.78 – 1.97 and it will increase after grinding process 2.22 – 2.78. It increases because the grinding process decrease the porosity with reduces the particle sizes. The particle size and shape of ground and unground POFA are different. Unground POFA is large, spherical and porous. Ground POFA is consisting of crushed particle with irregular and angular shape same goes to ordinary Portland cement (OPC). For chemical composition, POFA contain SiO_2 in about 44-66%. Other pozzolanic components are Al_2O_3 and Fe_2O_3. Tangehirapat et al. (2009) stated that the chemical composition of POFA satisfies the requirement for Class N pozzolanic material stated in ASTM C618-08a (2008).

Ground palm oil fuel ash (POFA) has high fineness and it will improve the mechanical properties and durability of concrete that contain the high amount of recycled concrete aggregates. Ground palm oil fuel ash (POFA) has high fineness and it will improve the mechanical properties and durability of concrete.

Awal & Hussin (1997) stated that using POFA as partial cement replacement in concrete can increase in chemical resistance to acidic environment. In addition, although higher alkaline content POFA, it has been effective suppressing the expression due to alkali – silica reaction.

In the modern era, the concrete produced contains multi components that have one or more admixture in addition to the four basic ingredients in the manufacturing of concrete which are cement, aggregates, water and sand. For each component, one has options that can affect the price of the product and service behavior. However between the constituent components, cement or cementitious materials play an important role in the production of concrete is strong and durable.

1.2 Problem Statement

Palm oil processed resulted in the accumulation of waste such as POFA and OPS. As time goes on more and more waste material were collected and waste disposal zone is become limited. It is a major problem because this waste cannot be reused and recycle.

The use of Portland cement in concrete construction leads to a very high carbon dioxide released into the atmosphere during the production of cement. Lately, efforts to increase the use of fly ash to partially replace the use of Portland cement in concrete is increasing. Most of the material is dumped in landfills where it will cause environmental pollution. Geopolymer concrete is a new material that does not require Portland cement as a binder. Instead, the source of materials such as fly ash, which is rich in Silicon (Si) and aluminum (Al), are activated by alkaline liquids to produce the binder. So OPC is not required.

1.3 Objectives of the Study

The objectives of the study are:

i. To determine the optimum proportion of palm oil fuel ash in fly ash based geopolymer concrete containing oil palm shell ;
ii. To determine the compressive strength of palm oil fuel ash in fly ash based geopolymer concrete containing oil palm shell; and
iii. To determine the porosity of the testing cube.

1.4 Scope of study

This study concentrated on inverstigation of compressive strength and split tension of concrete of fly ash based by replacing certain percentage of aggregate with palm oil fuel ash (POFA) combined with oil palm shell (OPS) with certain propotion and geopolymer concrete as a control. The geopolymer concrete contain of aggregate, sand, sodium hydroxide, sodium silicate, flyash and water were consider as a control mix without replacing with POFA (0%) and OPS (0%). Six series of mixes comprises of 10 %, 20 % POFA and 12.5 % of OPS. Every mix except were poured with 41 kg/m^3 of 8 mol of sodium hydroxide (NaOH).

The samples were created in the form of cube. The concrete were cast and poured into the mould and the hardened concrete was taken out from the mould after 24 hours. The hardened concrete was cured in the surrounding temperature, at 60°celcius and 80°celcius. The concrete was cured for 1, 7, and 28 days for every mix. The compressive strength test were began after all the specimen were matured due to the curing process. On the other hand, the porosity of the testing cube for every day of testing also were considered.

1.5 Significant Of Study

Concrete has an important role in the beneficial use of these materials in construction. Many innovation, modification and developments have been made to place industrial waste such as concrete itself and waste material like POFA and OPS as a cement replacement. This research is to investigate the optimum proportion of POFA and OPS in order to have the strong and durable concrete.

The main goals of sustainable waste management are to maximize reuse and recycling. Recycling is a best way for materials not suitable for composting. In order to reduce waste and pollution and to recycle as much as possible, the concrete industry has started a few method to achieve the goals.

CHAPTER 2

LITERATURE REVIEW

I. Introduction

The world now faces a lack of essential resources, although human have limited use against it. Depletion of resources has played a part, although not distinctive to the destruction of past civilizations and now impends to drive "the destruction of global society as a whole" (Diamond, 2006). Of particular concern is the fact that the oceans and as the Arctic permafrost soils are expanding, when temperature increases, drowned into sources of CO2 and methane, threatening a fatal increase the greenhouse effect (Pearce, 2007).

The factors that contribute to this phenomenon is the use of Portland cement in concrete construction heading to a very high carbon dioxide released into the atmosphere when the production of cement (Dickson, 2002). Recently, efforts to increase the use of fly ash to partly replace the use of Portland cement in concrete have risen. Most of the material is dumped in landfills and it will cause the environmental pollution. One of the methods that can be done to cope with this situation is to produce geopolymer concrete. Researches from Yasuhiro Dosho (2007) signify the geopolymer concrete is an economically advantageous material exhibiting an excellent resist.

In order to yield the geopolymer concrete, that is by utilizing wastes from agricultural sector, palm oil industry to be specific. Palm Oil Fuel Ash or known as POFA have the potential to be used as recycle construction materials as pozzolans. Aimin (1997) once stated that POFA is the ashes yielding from husk fiber and shell of palm oil burning by generation plant boiler which create energy to be utilized in a palm oil mill in order to get palm oil.

POFA is discovered to have a high pozzolanic material, can be used as a fractional cement substitution, increase the compressive strength and durability of concrete. Oil palm shell (OPS), has yielded more than 4 million tonnes annually in our country which could be utilized as the alternatives of renewable resource in the construction industry. More buildings can be constructed as alternative for different groups of people when the oil palm shell known as OPS was applied in construction. It can substitute the natural course aggregate in concrete production.

2.I.1 Alkaline Solution

Alkaline solution commonly used in geopolymer concrete is sodium silicate and potassium hydroxide. Typically, one of the solution was mixed with sodium hydroxide to produce alkaline solution and the molarity is between 7M to 10M. The alkaline solution commonly prepared 24 hours before start mixing with the fly ash.

The optimum ratio of sodium silicate to sodium hydroxide is 0.67 – 1.00 (Chindaprasirt et al. (2007)). For the Sodium hydroxide, he said that the concentration of NaOH between 10M to 20M give the smallest effect on the strength.

2.1.2 Curing Process

The most important factor for geopolymer concrete is about the curing temperature. The setting time of the geopolymer concrete will decrease when the curing temperature increase (Chanh et al., 2008). Polymerization process was occurring during the curing process. Polymerization becomes more darting and geopolymer concrete can archive 70% of its strength in 3 to 4 hours curing due to the increasing of temperature. (Kong and Sanjayan, 2008).

2.2 Properties Of Geopolymer

2.2.1 Workability of fresh geopolymer

Geopolymer concrete also needs water because the use of water toward geoplymer concrete will improve the workability, but the porosity also will increase due to the evaporation of water during curing process (Sathia et al., 2008).

When sodium hydroxide and sodium silicate concentration increase it will reduce the flow of mortar. Range of the workable flow is 110 ± 5 to 135 ± 5 %. (Chindaprasirt et al., 2007). Superplastisicer and extra water can be added to improve the workability of mortar. Extra water can give higher strength compare to the addition of superplasticiser.

2.2.2 Compressive strength

The compressive strength is depending on the curing temperature and curing time. Curing time and curing temperature is directly proportional to the compressive strength. The compressive strength of geopolymer concrete can be obtain about 400 to 500 kg/cm^2 with the range of 60 - 90 ° C of curing temperature and 24 hour to 72 hour of curing time (Chanh et al., 2008). It is also depend on the content of flyash fine particle.

The finest of the flyash also influence the compressive strength of the geopolymer concrete. When the flyash more fine, the compressive strength also will increase. By using the sodium hydroxide as an activator the highest compressive strength will be obtain. (n = 1.5; 10% Na_2O). So, sodium silicate is very suitable to use as alkaline activator because it include the dissolve and partially polymerized silicon which reacts easily, incorporates into the reaction products and significantly contributes to improving the mortar characteristics (Komljenovi'c et al., 2010).

2.2.3 Resistance against aggressive environment

Flyash based geopolymer concrete provide resistance against aggressive environment which is it can be used to construct the building or structure that exposed to marine environment (Chanh et al., 2008). 0.5% of weight will be lost due to exposure to the acid solution compare to the normal concrete which is 3% when immersed in sulphuric acid. (Sathia et al., 2008)

2.3 Behaviour of geopolymer at elevated temperature

Other properties that are constantly considered for the safety of user are fire resistance of concrete. Kong and Sanjayan (2008) once said that the ratio of fly ash to alkaline solution affect the general strength and fire resistance of geopolymer. It was discovered that the fly ash-based geopolymer shows increase in strength after the exposure of temperature.

The behaviour of geopolymer concrete under elevated temperature affected bythe size of aggregates that being observed by Kong and Sanjayan (2010). The aggregate with miniature sized (<10mm) could lead to spalling and also vast cracking of geopolymer but the greater the aggregate (>10mm) were more stable it is. Moreover, the thermal incompatibility between the geopolymer matrix and its aggregate components was the most cause of reason of strength loss in geopolymer concrete specimens at increasing temperature. It can be shown by comparison between geopolymer concrete with higher temperature. So then,the expansion of aggregate with respect to temperature was a factor that controls the performance of geopolymer.

The thermal stability of the geopolymer materials prepared with sodium containing activators was comparatively low and significant changes in microstructure occurred that was observed by Bakharev (2006). The strength of the concrete was lowered at 800°C due to the elevated in the average pore size where amorphous structures were substituted by the crystalline Na-feldspars. The turn over situation was observed when potassium silicate was chose as activators as it can remain often amorphous up to 1200°C. The average pore size was reduced and the compressive strength of geopolymer was improved after the firing of those materials. There is a high shrinkage along changes in compressive strength with elevated fired temperature in the range 800 to 1200°C when fly ash based geopolymer is prepared using class F fly ash with sodium and potassium silicate,stated by Bakharev, 2006.

2.4 Introduction of POFA

Palm oil is reddish in colour edible vegetable oil derived from the pulp of the oil palms with high beta-carotene content. It is semi-solid at room temperatures in the forms of glyceryl laurate (saturated and unsaturated fats). Various palm oil products are made using refining process and every industrial process should have a by-product that comes along with the product. As for the palm oil, palm oil fuel ash is the by-product produced in palm oil mill. Both palm oil husk and palm oil shell are burned as fuel in the boiler of palm oil mill as soon as the palm oil is extracted from the palm oil fruit. According to Sata et. al., 2004, after combustion about 5% palm oil fuel ash by weight of solid wastes is produced. The ash produced seldom differs in colour from grey to darker shade depends on the content in it which is carbon. This means that, the physical characteristics of POFA is very much be affected by the operating system in palm oil factory.

At present, Malaysia is currently holds 39% of world palm oil production and 44% of world exports. By being the one of the largest producers and exporters of palm oil products, POFA produced in Malaysia palm oil mill is dumped as waste without any profitable return, stated by Sumadi & Hussin (1995). The disposal of POFA is still being conducted without being out for any other useful purpose as compared to other type of palm oil by-product. As Malaysia is proceeding to increase production of palm oil, there will be more ashes produced and any default in finding solutions in making use of this by-product will create an extreme environmental problem.

2.5 POFA a new pozzolanic material

As a fact, 4.49 million hectares of land in Malaysia is under oil palm cultivation which producing tonnes of palm and palm kernel oil. Malaysia itself is one of the largest producers and exporters of palm oil in the world, which hold about 11% of the export trade of oils and fats internationally. By means of these statistics, on average there are 43 tonnes or more empty fruit shells, bunches and fibres generated per 100 tonnes of fresh fruits bunches processed. It is approximately counted that the total solid waste generated by this respective industry has calculated to more than 8 million tons a year, stated by Rashid & Rozainee, (1993). Steam that produced for electricity generation and palm extraction process comes from boiler fuel which is the palm fibre and shell obtained as waste products by the industry. The problems that occur mostly because of the waste product from the burning of palm fibre and shell that produced ashes. Commonly, this ash is dumped into wastelands behind the mill. However, studies have shown that this ash has good pozzolanic properties that make possible the substitution of cement in mortar and cement mixes. These ashes may also identify with various name such as palm oil fly ash (Samsuri & Subbiah, 1997) and oil-alm ash (Tay, 1990).

2.6 Chemical composition of POFA

POFA is indicated as a pozzolanic material by both the analysis of physical and chemical properties (Sumadi & Hussin, 1993). This pozzolanic material can be grouped accordingly to Class C and Class F as specified in (ASTM C618-92a, 1994). The silica content is moderately rich while the lime content is very low as compared to that in OPC (Awal & Hussin, 1997). Still, the chemical composition of POFA can be differed due to operating system in palm oil mill.

2.7 Strength and durability of POFA

Starting from the time the palm oil fuel ash that been considered worthless successfully discovered can actually be made used in construction industry especially in concrete technology onwards, POFA that been used in concrete production continued to be studied and revealed by researches across Asia. Up to now, some researches Sata et al., (2004) that has been determined studying on POFA use has able to successfully discover the benefits of POFA in concrete technology in terms of upgrading towards the properties of concrete either durability or strength aspect.

The pioneer in POFA research, Abu (1990) has started on studying agricultural ash in Malaysia and at last acknowledge that POFA is a pozzolanic material and capable to be substitute as partial cement substituent up to 35% in mortar mix that could exhibit same strength as control mortar. Awal & Hussin, (1996) have continued the studies that highlighted that POFA concrete gain maximum strength when 30% of the cement was replaced with POFA. The maximum strength gain occurred at the replacement level of 30% as reported but further increase in the ash content would decrease the strength of concrete gradually. But yet, POFA performance once added in concrete still have to be studied to gain the result. In addition, the increasing in fitness of POFA would bring to a higher concrete strength development than the coarser one (Awal & Hussin, 1996).

2.8 Pozzolanic as cement substitute

At present, of all the silicon by-products, POFA are possibly the most widely use globally. Besides, added to this is the fact that POFA makes considerable changes to the strength and durability aspects of concrete that are well documented in national codes and standards. In addition, there isn't any disbelief that the replenishment of pozzolanic material, both naturally occurring or artificially made, as a partial cement substitution passes on substantial enrichment of the vital characteristics of the resulting mass whether in its hardened or fresh states.

Lately, cement substitutes have been made by using ashes from agricultural source like coconut husk, palm oil husk, rice husk,peanut shell or fibre shell etc (Bentur et al., 1986). Among these ashes, rice husk ash (RHA) is greater rich and has been claimed as the most active pozzolan in making greater performance concrete and cement products. Before this, plenty of works have been done to discover the various aspects of ashes with pozzolanic behaviour and in several parts globally, these materials have already been known as additional cementing materials.

2.9 Application of Pozzolanic in concrete

In building construction, concrete is a vital material needed as a basic process. It is consists of chemically inert particulate and hard substance that also known as